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OPTIMALLY SCHEDULING INSTRUCTORS AT THE DEFENSE LANGUAGE INSTITUTE: AN INTEGER PROGRAMMING APPROACH

by

David S. Kunzman

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Thesis Advisor: Robert F. Dell

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The Defense Language Institute (DLI) teaches various levels of foreign language competency to Department of Defense personnel. It currently offers 104 courses ranging in length from 2 to 63 weeks in 23 languages. There is a mandated instructor-to-student ratio,which determines the number of sections of each course that must be taught each year. This thesis develops linear integer programs to decide when to start each section of each course. The primary objective guiding the integer programs is the minimization of the full-time staff of instructors required to meet the next three years' projected student input. Secondary objectives are used to improve the face validity of the models' recommendations. When compared with manual methods, decisions developed using the models are superior to current decisions for all measures of effectiveness considered, and they provide DLI with a savings opportunity in excess of $6.5 million over the next three years.

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OPTIMALLY SCHEDULING INSTRUCTORS AT THE DEFENSE LANGUAGE INSTITUTE: AN INTEGER PROGRAMMING APPROACH

by

David S. Kunzman
Captain, United States Marine Corps
B.S., Oregon State University, 1987

Submitted in partial fulfillment
of the requirements for the degree of

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Author: ______________________
David S. Kunzman

Approved by: ______________________
Robert F. Dell, Thesis Advisor

Richard E. Rosenthal
____
Richard E. Rosenthal, Second Reader

____
Peter Purdue, Chairman
Department of Operations Research

ABSTRACT

The Defense Language Institute (DLI) teaches various levels of foreign language competency to Department of Defense personnel. It currently offers 104 courses ranging in length from 2 to 63 weeks in 23 languages. There is a mandated instructor-to-student ratio, which determines the number of sections of each course that must be taught each year. This thesis develops linear integer programs to decide when to start each section of each course. The primary objective guiding the integer programs is the minimization of the full-time staff of instructors required to meet the next three years' projected student input. Secondary objectives are used to improve the face validity of the models' recommendations. When compared with manual methods, decisions developed using the models are superior to current decisions for all measures of effectiveness considered, and they provide DLI with a savings opportunity in excess of $6.5 million over the next three years.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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EXECUTIVE SUMMARY

The optimization models developed in this thesis for course scheduling at the Defense Language Institute (DLI) provide DLI with a savings opportunity in excess of $6.5 million over the next three years.

DLI teaches various levels of foreign language competency to Department of Defense (DoD) personnel. It currently offers 104 different courses ranging in length from 2 to 63 weeks in 23 languages. There is a mandated instructor-to-student ratio, which determines the number of sections of each course that must be taught each year. The DLI scheduler must decide when to start each section of all courses. This thesis develops integer programming optimization models to help the scheduler create a three year schedule for each language.

The known yearly model inputs are: course length, student totals, course section totals and the number of instructors per section for each course. The optimization models adhere to all the constraints and guidelines that the DLI scheduler must follow. These include:

- Instructors are scheduled for at most one section at a time.
- Only full time instructors are employed.
- Instructors are employed for a full year.
- DLI observes a two-week break every December.

- Sections extending over the December break must remain in session until at least the third week of January.
- Sections cannot be scheduled to start the last two weeks of November or in December.
- No more than three sections of a course may start in any week.

Since instructors teach only one language and there are ample classrooms and living quarters, we can schedule each language independently. This is a fortunate simplification for the modeling process.

The primary objective function guiding the optimization is to minimize the number of instructors needed to meet student demand. Secondary objectives are to:

- Minimize the differences in year-to-year instructor totals, thus reducing potential firing and hiring.
- Maximize the number of three section starts.
- Minimize instructor down time.

The optimization model developed is called OSI (Optimally Scheduling Instructors) for DLI. OSI produces face valid three year schedules in less than three hours for each language on the Naval Postgraduate School AMDAHL 5990-700A mainframe. OSI's schedules are better than the manually developed schedules in all areas of concern: they use fewer instructors, they are less turbulent in terms of year-to-year instructor turnover, and the time required to produce a schedule is significantly less. When OSI was run using the expected DLI student input for fiscal years 1994, 1995 and 1996 and compared to manual schedules, it resulted in a

decrease of 111 instructors over a three year period. This decrease, evaluated at the salary and benefits of a GS-9 (Step 5), yield a potential savings in excess of $6.5 million to DLI.

I. SCHEDULING PROCESS

A. DEFENSE LANGUAGE INSTITUTE, FOREIGN LANGUAGE CENTER

The Defense Language Institute, Foreign Language Center (DLI) trains Department of Defense (DoD) personnel in various levels of foreign language competency. It currently offers 104 different courses ranging in length from 2 to 63 weeks in 23 languages. The United States Armed Forces and several federal agencies are awarded yearly quotas' for each of these courses, based on their projected requirements. The next three year total yearly projected requirements for each course is maintained using the Army Training Requirements Resource System (ATRRS).

ATRRS reports on each language individually, which coincides with language autonomy at DLI. Due to specific dialect requirements within each language, instructors are hired to teach only one language. This, along with ample classroom space and living quarters allows each language to operate independently. Each language at DLI contains a department office. This office is responsible for the placement of students to classrooms and instructors to courses in support of a "Master Schedule."

Master Schedule and other terms are defined to provide clarification for the reader:

- Language - an area of study at DLI,
- Course - a specific topic of study within a language, such as basic or advanced,
- Section - a group of 10 or fewer students who are scheduled to take a specific course together,
- Master Schedule - a list that contains the year's weekly section start dates for each language,
- Instructor Year - the employment of one instructor for one year.

1. Scheduler Responsibility

The Master Schedule is produced by the Operations, Plans and Doctrine Plans Scheduling office. A Scheduling Administrator and Program Analyst are responsible for producing a Master Schedule based on the ATRRS requirements. The scheduling administrator (scheduler) is responsible for:

- Coordinating and verifying ATRRS requirements,
- Publishing a Master Schedule for each fiscal year,
- Determining appropriate instructor levels for each language's department based on ATRRS requirements and the Master Schedule,
- Resolving problems identified by the language departments after publication of the Master Schedule.

The program analyst is responsible for:

- Reviewing the Master Schedule,
- Identifying language programs that can be more cost effectively supported at DLI,
- Coordinating distribution of instructor requirements within DLI.

B. COURSE SCHEDULES

ATRRS provides the scheduler with the length of each course and the expected yearly student input for each course. DoD mandates each section of a course contain no more than 10 students and have exactly two instructors. Sections that contain five students or less are allowed with only one instructor but sections of 10 students are preferred. The instructor-to-student ratio and the student load determine the number of sections of each course each year.

Certain restrictions are placed on the scheduler when deciding section starts. The following apply to instructor use:

- Instructors are scheduled for at most one section at a time.
- Only full time instructors are employed.
- Instructors are employed for a full year.

The following apply to section starts:

- DLI observes a two-week break every December.
- Sections extending over the December break must remain in session until at least the third week of January.
- Sections cannot be scheduled to start the last two weeks of November or in December.
- A maximum of three sections of a course may start in any week.

Subject to these restrictions, the scheduler attempts to produce a schedule with the minimum number of instructor years. The scheduler also attempts, as long as it does

not increase instructor years, to start three sections of one course together.

C. CURRENT MANUAL SCHEDULING PRACTICES

The scheduler currently uses a Lotus 123 spreadsheet (Lotus Development Corporation, 1989) to manually create a master schedule based on the ATRRS data. It takes approximately six weeks to produce the master schedule, and it is done 18 months ahead of the execution year. The master schedule is then updated six months before execution, and quarterly thereafter. Upon execution, the master schedule receives weekly updates as needed. The master schedule's instructor totals are reviewed quarterly to decide on the need for addition or termination of instructors.

D. OBJECTIVE OF CURRENT RESEARCH

The objective of this thesis is to develop and solve optimization based models to produce a master schedule for DLI. The models determine section starts on a weekly basis for the three years of ATRRS provided data. This allows the scheduler to generate a master schedule, while easily updating weekly results.

The models of this thesis are formulated and solved using GAMS (Brooke et al., 1992) and XA (Sunset Software, 1987) on the Naval Post Graduate School (NPS) AMDAHL 5990-700A

mainframe. DLI has access to the NPS mainframe and available software, allowing them to implement the model at no cost.

E. THESIS OUTLINE

Chapter II surveys related classroom scheduling models. Chapter III presents the mixed linear integer programs developed to assist the scheduler produce a master schedule, with detailed discussion of the various measures of effectiveness addressed. Using the models of Chapter III, computational performance using DLI data is presented in Chapter IV. Conclusions are provided in Chapter V.

II. PREVIOUS COURSE SCHEDULING RESEARCH

A. TIMETABLING MODELS

The operations research literature often reserves the term scheduling for machine scheduling problems and refers to all other related problems as timetabling. We adhere to this convention in this section but in other parts of this thesis we adopt the DLI scheduling terminology.

The operations research literature contains numerous timetabling problems, however, none of them addresses a problem similar to that of this thesis. Two related models are course timetabling and examination timetabling. These timetabling problems are both concerned with a fixed work force, in contrast to the DLI problem which seeks the appropriate size for the work force.

1. Course Timetabling

Course timetabling often involves situation in which students have requested a set of courses and the objective is to minimize the total number of conflicts (Carter, 1986). Other issues of concern include: maximizing use of classroom facilities and keeping course size constrained to an upper bound. The desired result is to obtain a schedule that works for both the instructors and students alike.

Findlay (1980) formulates the course timetabling problem with two objectives: schedule courses so as to maximize the number of students obtaining valid academic schedules and maximize the utilization of faculty and classrooms.

Thompson (1965) introduces a method for solving course timetabling problems that combines heuristic and algorithmic ideas. The heuristic decides the order in which to schedule students and sets up the mathematical problem. The assignment of students to courses is done using an integer program whose objective function minimizes the sum of course slack. The reported resulting schedule was considered better than manually produced schedules with an estimated 48 to 72 CPU hours (on 1965 hardware) required to schedule 15,000 students.

Tripathy (1980, 1984) defines course timetabling as the scheduling of a certain number of meetings, over a definite period of time, requiring certain resources in conformity with available resources. Tripathy formulates a version of the course timetabling problem as a linear integer program which is solved using Lagrangian relaxation.

2. Examination Timetabling

In examination timetabling, examinations must be scheduled to a fixed number of periods so that no student is required to take more than one examination at a time. Examination timetabling must be conflict free, examination

periods must be non-overlapping and of uniform size (Carter, 1980). Secondary constraints include: limitations on the number of students, consecutive examination constraints and equal distribution of exams over the exam period.

Cole (1964) published an algorithm modifying the vertex coloring algorithm to introduce the constraints of: certain sets of exams must be consecutive, precedence ordering for some exams, space constraints on room sizes and certain examinations could only be scheduled in the morning. The algorithm satisfies the "consecutive" constraints first and then uses the "largest degree first, fill from top" rule. Computational results were reported for a first year university program with 34 courses requiring examinations. Since some examinations scheduled required two periods a total of 57 examination periods were scheduled.

3. Problem Complexity

In a working paper, the results of which will be presented by Bulfin, Dell and Kunzman (1993), the computational complexity of the problem in this thesis is shown to be NP complete. The proof is based on reduction from a bin packing problem.

B. COMPUTER APPLICATIONS FOR SCHEDULING

The literature available on the application of computers for scheduling is varied and often directed to school administrators as an academic management issue. This section

discusses application and results, however, the methods and algorithms used to obtain the results are unknown. Most applications discuss the design of class schedules as the balancing of student needs, faculty interests, available facilities and funding levels. These applications stress the advantages to computer scheduling which include: optimal schedules, efficient use of faculty and facilities, quickly generated schedules and the ability to increase curriculum offerings.

1. Prior Scheduling Applications

Stauffer (1991) considers class scheduling "risky business" since schedules must be balanced to satisfy both student and faculty interests. Despite this observation computer technology has been used to aid schools in improving class schedules and has provided a means for a more efficient use of available resources.

A study involving 124 Wisconsin schools that use computers for scheduling (Krahn and Hughes, 1976) report: professional personnel time was reduced in 66.1% of the schools, better utilization of facilities in 54.1% of the schools, student balance in courses improved in 73.4% of the schools and 93.5% of the schools reported computer costs were justified.

Piele (1971) refers to Murphy and Sutters' (1964) comparison of the manual method of developing schedules with

the Generalized Academic Simulation Program (GASP). It is pointed out that computer scheduling allows considerable flexibility in setting parameters for the scheduling of courses, facilities and students. Computer scheduling using GASP reduced staff requirements to encourage the exploration of "what if" questions.

Piele (1971) references Allen and De Lays' (n.d.) discussion on the Stanford School Scheduling System (S-4) as the means to free administrators from the burden of scheduling without loss of opportunity to make vital educational scheduling decisions. S-4 provides the computer the freedom to choose a schedule reflecting the abilities and interests of students and special qualifications of instructors. It is reported in a few seconds, S-4 can investigate the millions of possible combinations of instructors, students and limits of time satisfying a high percentage of student schedule requests at a cost of $1 per student.

Stanford's field implementation of computer scheduling was at Virgin Valley High School in Nevada. Allan (1964) reports that the first year of operation yielded greater opportunities for individualized instruction, increased curriculum offerings, released time for teacher preparation and improved student and teacher attitudes toward learning.

III. DLI SCHEDULING MODEL

A. PROBLEM DESCRIPTION AND FORMULATION

The problem of creating a master schedule for DLI is formulated as separate mixed linear integer programs for each language. The formulations ensure all scheduling requirements are satisfied and decides weekly section starts for the three-year interval of ATRRS projected totals. Scheduling over a three year period allows the model to minimize changes in instructor year requirements from year to year.

The models enforce all guidelines the DLI scheduler must follow, which include: restrictions on instructor use and on section starts.

The restrictions on instructor use apply to all languages taught at DLI, and include:

- The use of full time instructors only (no part time instructors are employed),
- Instructor are employed on a yearly basis,
- Instructors can teach only one course at a time.

The restrictions on section starts include:

- DLI observes a yearly holiday period the last two weeks of December. This mandatory break allows the use of a 50-week year (weeks' 10 and 11 of each fiscal year are skipped when applying the results of the models' schedule),
- DLI restricts any courses from beginning one month before the two-week holiday. Courses may be scheduled to end during this period,

- The amount of preparation required for graduation impose restrictions on courses ending earlier than the third week after the two-week holiday.

- It is a standing preference among the DLI scheduling staff to schedule as many three section starts of a course as possible.

The mixed linear integer programs used to create a master schedule for each language consist of four objective functions. The primary measure of effectiveness directly translates into the first objective:

1. Minimize the number of instructor years.

The model with only this objective produces a face-valid schedule. Three additional objectives, are considered to better emulate the current DLI schedule:

2. Minimize turbulence in year to year instructor totals.
3. Maximize the number of three section starts.
4. Minimize instructor downtime.

A separate model is developed with each objective where the limited results of previous models are sequentially carried forward as data for the next model. The separate models allow the scheduler to implement the objectives in any order, provided the proper data entries are made.

The advantages of solving each objective independently include:

- It is computationally easier to solve,

- Provides flexibility, by giving the scheduler the ability to "What If" scenarios during any phase of the model,

- Some languages may require a fixed instructor year total negating the need to minimize instructor years,

- Schedule requirements may be such that three section starts are not an option when formulating course starts.

The resulting models are called OSI (Optimally Scheduling Instructors) for DLI. For clarity, OSI_k refers to the OSI model using only objective k (ie. OSI_1 is the model with objective one only).

B. OSI (OPTIMALLY SCHEDULING INSTRUCTORS) FOR DLI

The formulation of OSI_1 is presented below after the introduction of appropriate notation. Models using other objective functions follow identifying any new or changed notation.

INDICES:

i = course name;

y = schedule year (1-3);

t,t' = weeks' DLI is in session (1-150).

DATA:

$START_{it}$ = 1 if course i can begin in week t, 0 otherwise;

$PCDUR_t$ = number of sections in session during week t due to past scheduling decisions;

$SECTION_{iy}$ = sections of course i that require scheduling in year y;

$LENGTH_i$ = length in weeks of course i;

MAXSTART = upper bound on number of sections per course starting any week.

VARIABLES:

X_{it} = number of sections of course i to start in week t (integer);

$TMAX_y$ = maximum number of simultaneous sections meeting in year y (continuous).

EQUATIONS:

$$Minimize \sum_y 2 \times TMAX_y$$

Subject to:

$$\sum_{t=(1+50(y-1))}^{50y} X_{it} \times START_{it} = SECTION_{iy} \qquad \forall iy \qquad (1)$$

$$\sum_i \sum_{t'=t-length_i} X_{it} \times START_{it} + PCDUR_t \leq TMAX_{\lfloor (t-1)/50 \rfloor + 1} \qquad \forall t \qquad (2)$$

$$X_{it} \times START_{it} \leq MAXSTART \qquad \forall it \qquad (3)$$

CONSTRAINT EXPLANATION:

(1) Yearly section requirements for course i must be scheduled.

(2) Defines maximum number of simultaneous sections meeting in any week t for each year y.

(3) Limits the maximum number of sections of any course, to start in week t to be less than or equal to MAXSTART.

The upper bound on section starts per course represented by constraint (3) is a DLI scheduler request that can be violated. It is modeled as a hard constraint in the above formulation and is subsequently relaxed in OSI_3 and OSI_4.

The objective function minimizes the instructor years (TOTINST) required for the three-year interval. TOTINST is included as an upper bound in OSI_2 which contains a constant $SMOOTH_y$, to help reduce changes in instructor year totals between scheduled years.

OSI_2 is presented below after the introduction of new and changed notation.

<u>DATA</u>:

TOTINST = Maximum number of instructors required for the three year period;

$TMAX_0$ = Half of the number of instructors employed for the year prior to the models planning horizon.

<u>VARIABLES</u>:

$HIRE_y$ = Number of instructors that need to be hired at the end of year y;

$FIRE_y$ = Number of instructors that could be fired at the end of year y.

EQUATIONS:

$$MINIMIZE \sum_{y} SMOOTH_y (HIRE_y + FIRE_y)$$

Subject to:

(1), (2) and (3)

$$2(TMAX_y - TMAX_{y-1}) \leq HIRE_y \qquad \forall y \qquad (4)$$

$$2(TMAX_{y-1} - TMAX_y) \leq FIRE_y \qquad \forall y \qquad (5)$$

$$\sum_{y} 2 \times TMAX_y \leq TOTINST \qquad (6)$$

CONSTRAINT EXPLANATION:

(4) Defines needed instructor hiring for year y.

(5) Defines possible instructor firing for year y.

(6) Instructor year total cannot exceed a maximum.

OSI_2 helps minimize the amount of turbulence in instructor year totals from year to year. It is needed since a solution employing 16, 17, 18 instructors for three years with a total of 51 instructor years is undifferentiated in OSI_1 from a solution of 17, 17, 17. The objective function parameter $SMOOTH_y$ is discussed later in this chapter.

The OSI_3 model uses a parameter $STACKIT_{sit}$ to help maximize the number of three section starts. OSI_3 is presented below after the introduction of any new or changed notation. The notation changes are primarily caused by the use of a third index which defines the number of simultaneous section starts.

INDICES:

s = number of sections to simultaneously start (1-3).

DATA:

$STACKIT_{sit}$ = value of starting s section(s) of course i in week t;

$TMAX_y$ = one half of the instructor year total for year y (output from OSI_2);

$SEC3MAX_{iy}$ = maximum number of three section starts for course i in year y.

BINARY VARIABLES:

X_{sit} = 1 if s section(s) of course i start in week t; 0 otherwise.

EQUATIONS:

$$Maximize \sum_{s}\sum_{i}\sum_{t} STACKIT_{sit} \times X_{sit}$$

Subject to:

$$\sum_{s} \sum_{t=(1+50(y-1))}^{50y} s \times X_{sit} \times START_{it} = SECTION_{iy} \qquad \forall iy \quad (7)$$

$$\sum_{s} \sum_{i} \sum_{t'=t-length_i}^{t} s \times X_{sit} \times START_{it} + PCDUR_t \leq TMAX_{\lfloor (t-1)/50 \rfloor + 1} \quad \forall t \qquad \textbf{(8)}$$

$$\sum_{t=(1+50(y-1))}^{50y} X_{3it} \leq SEC3MAX_{iy} \qquad \forall iy \qquad \textbf{(9)}$$

<u>CONSTRAINT EXPLANATION</u>:

(7) Equivalent to constraint (1) reformulated for the redefined decision variable.

(8) Equivalent to constraint (2) reformulated for the redefined decision variable.

(9) Sets upper bound on the number of three section starts for each course i in each year y.

Constraint (9) provides cutting planes that reduce possible fractional variables in the linear programming relaxation of OSI_3. For example, if 11 sections require scheduling, then there are at most 3 three-section starts possible. Without cutting planes, the remaining two sections would be encouraged to have some $X_{3it} = 2/3$ in the linear programming relaxation.

Unlike OSI_1 and OSI_2 the number of simultaneous section starts per course per week is limited to six in the above formulation (three sections $X_{3it} = 1$, two sections $X_{2it} = 1$ and one

section X_{1it}= 1). Explicit constraints could be added to limit this possibility but were not needed in practice.

The objective function coefficient of OSI_3, $STACKIT_{sit}$, is discussed later in the chapter. The number of three section starts ($NUM3SECT_{iy}$) determined by OSI_3 each year is used as a lower bound in OSI_4. OSI_4 uses the constant $PUSHBACK_{sit}$ to reduce instructor down time.

OSI_4 is presented below after the introduction of new and changed notation.

<u>DATA</u>:

$NUM3SECT_{iy}$ = number of three section starts (output from OSI_3);

$PUSHBACK_{sit}$ = value of starting s section(s) of course i in week t.

<u>EQUATIONS</u>:

$$Maximize \sum_s \sum_i \sum_t PUSHBACK_{sit} \times X_{sit}$$

Subject to:

(7) and (8)

$$\sum_{t=(1+50(y-1))}^{50y} X_{3it} \geq NUM3SECT_{iy} \qquad \forall iy \qquad \textbf{(10)}$$

CONSTRAINT EXPLANATION:

(10) Sets the lower bound on the number of three section starts for each course i in each year y.

The objective function maximizes instructor usage based on a fixed number of instructors thus eliminating instructor down time. The value of $PUSHBACK_{sit}$ is discussed below.

C. OSI OBJECTIVE FUNCTION COEFFICIENTS

A number of values were investigated for the objective function coefficients in OSI_2, OSI_3 and OSI_4. Below the values used in Chapter IV and alternate forms are discussed.

1. OSI_2 Objective Function Coefficients

The objective function in OSI_2 uses a constant $SMOOTH_y$ to account for each years relative importance. Values of $SMOOTH_1 = 100$, $SMOOTH_2 = 10$ and $SMOOTH_3 = 1$ are used in the model for results reported in chapter IV. These values place the emphasis on year one's instructor level (the year with the most accurate data) as an order of magnitude more important than any other year. These values empirically helped the model provide a smooth transition from previous instructor year totals into the models implementable instructor year totals.

2. OSI_3 Objective Function Coefficients

The objective function in OSI_3 uses a constant $STACKIT_{sit}$ to account for three section starts in each successive year. Values of $STACKIT_{3i1} = 100$, $STACKIT_{3i2} = 10$ and

$STACKIT_{3i3}$= 1 are used in the model for results reported in chapter IV. These values, like those in OSI_2, emphasize year one's three section starts (the year with the most accurate data) as an order of magnitude more important than any other year.

The objective function for OSI_3 was reviewed using several other methods in an attempt to maximize three section starts. These methods include:

(1) Maximizing X_{3it} across a three year period without any weighting,

(2) Weighting only year one's three section starts,

(3) Weighting the first two years three section starts.

None of these alternative weightings empirically provided better results for year one's three section starts.

3. OSI_4 Objective Function Coefficients

The objective function coefficient in OSI_4, $PUSHBACK_{sit}$, is based on the minimum of 1 and $(50y-t)/length_i$ (the percent of each course completed during the scheduled fiscal year). As an example, a 20-week course starting in week 132 of a 150-week schedule would receive a fractional value of 18/20. This provides the solver the incentive to complete as much of a course as possible during the year in which it starts.

Included in $PUSHBACK_{sit}$ is a multiplicative constant to account for the year and number of simultaneous section starts. The weighted values for 3, 2 and 1 section starts

were; 300, 200, 100 (Year 1); 30, 20, 10 (Year 2) and 3, 2, 1 (Year 3).

Several other methods have been explored for the values of $PUSHBACK_{sit}$. These methods concentrated on minimizing the instructor down time by weighting:

- Year 1 starts only,
- Year 2 starts only,
- Year 3 starts only,
- Year 1 and 2 starts only,
- Year 2 and 3 starts only.

The weighting of year 3 starts provided promising results for several languages with short course lengths (< 50 weeks). However, none of the other methods empirically provided superior results for all languages.

An alternate objective of maximizing the completion of as many courses as possible before the end of the fiscal year was considered for OSI_4. Unfortunately, overlap is inevitable for most schedule years and the explicit maximization of the number of completed courses during the fiscal year empirically produces a non-implementable schedule. The reason for this can be explained with a simple example. Consider a 50-week schedule in which two 15-week courses and two 36-week courses must be scheduled. Figure 1 shows an optimal solution based on OSI_4. If the objective function were to maximize the number of course completions, an optimal solution using the

same data is shown in Figure 2. Maximizing the number of course completion produces significantly more overlap and idle time.

REDUCING INSTRUCTOR DOWN TIME

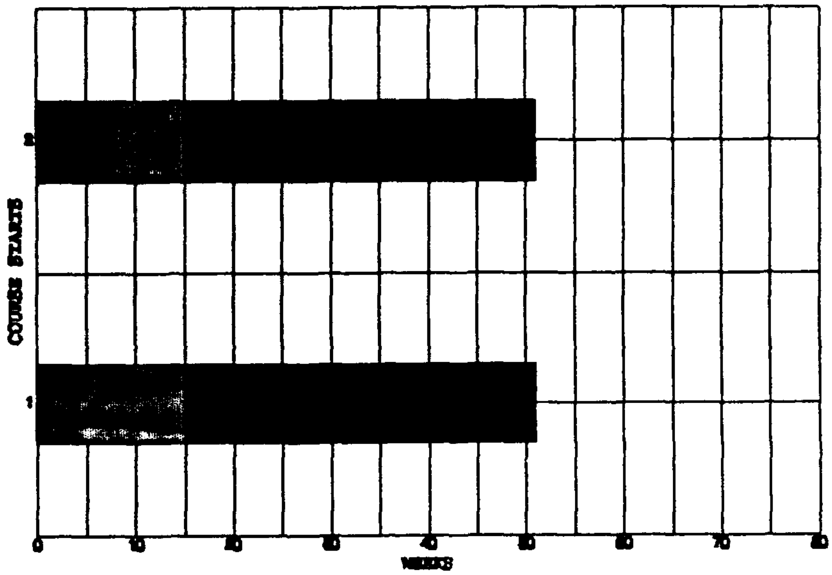

Figure 1

RESULTS OF MAXIMIZING COURSE COMPLETIONS

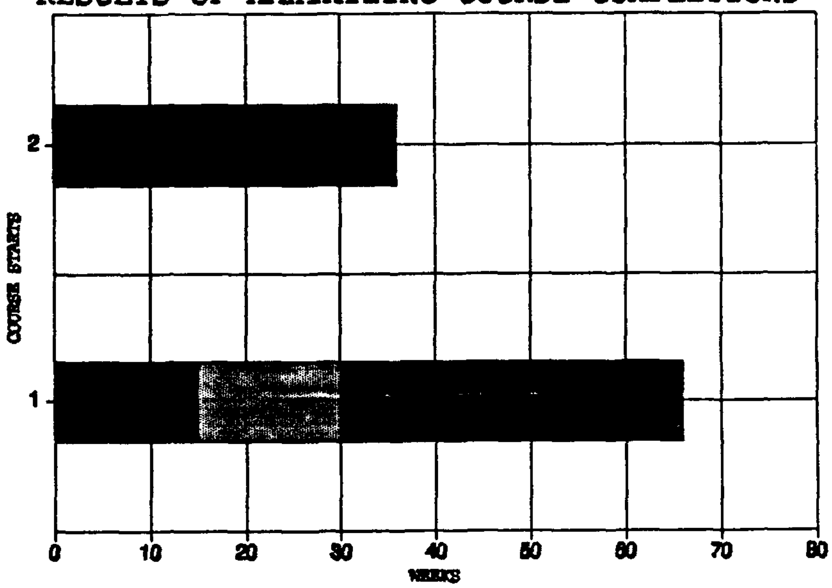

Figure 2

IV. COMPUTATIONAL EXPERIENCE

A. TEST PROBLEMS

DLI offers instruction in 23 languages shown in Table 1 ordered by 1994 section totals. Of these languages, 19 were solved using the OSI model. The other four languages require few instructors and are easily scheduled manually. As shown in Table 1, the number of courses vary with each language over the range from one to eight different courses and the course lengths range from 2 weeks to 63 weeks.

Three languages (Arabic, Spanish, and German) of the 23 were chosen for extensive OSI testing. The criteria used in choosing these three included the variation in course lengths, the number of sections requiring scheduling, the number of courses offered, and conversations with the DLI scheduler and program analyst. The linear integer program size of each representative data set varies with the version of OSI as summarized in Table 2. All tests of OSI are done using DLI data for fiscal years 1994, 1995 and 1996, shown in Table 3. The software used to implement OSI is GAMS (Brooke et al., 1992) for model formulation and XA (Sunset Software, 1987) for model solution. OSI was run on the NPS AMDAHL 5990-700A mainframe under the VM operating system.

TABLE 1

FY 94 LANGUAGE CHARACTERISTICS

This table shows the relative size and diversity of the languages taught at DLI for fiscal year 1994.

Language	FY 94		Course Lengths	
	Courses	Sections	Minimum	Maximum
Russian	8	63	2	47
Arabic	8	60	2	63
Spanish	6	60	2	25
Korean	6	35	2	63
Chinese	3	17	47	63
German	7	13	2	34
French	4	10	2	25
Czechoslovakian	6	9	2	47
Vietnamese	5	8	2	47
Persian	5	8	2	47
Polish	5	8	2	47
Japanese	6	6	2	63
Turkish	6	5	2	47
Thai	4	5	16	47
Italian	5	4	2	25
Hebrew	4	4	2	47
Ukrainian	2	3	2	47
Tagalog	5	3	2	47
Portuguese	4	3	8	25
Dutch	3	2	18	25
Greek	4	1	16	47
Belorussian	1	1	47	47
Serbo-Croatian	0	0	12	12

TABLE 2

OSI MODELS SIZE

German, Spanish and Arabic for fiscal years 1994, 1995 and 1996 are used for extensive OSI testing. These OSI models possess the following characteristics.

Language	OSI_k	Variables	Constraints	Non-zeros
German	1	438 (Integer)	172	21060
	2	438 (Integer)	179	21084
	3	700 (Binary)	175	63919
	4	700 (Binary)	175	65956
Spanish	1	620 (Integer)	172	18949
	2	620 (Integer)	179	18973
	3	1070 (Binary)	180	57836
	4	1070 (Binary)	180	59873
Arabic	1	645 (Integer)	175	44861
	2	645 (Integer)	182	44885
	3	1419 (Binary)	186	135872
	4	1419 (Binary)	186	138200

TABLE 3

SUMMARIZED LANGUAGE REQUIREMENTS IN TEST DATA

Fiscal years 1994, 1995 and 1996 course sections needing scheduling based on projected student input.

Language	Course Length	Number of Sections to Schedule		
		1994	1995	1996
German	34	10	8	9
	26	1	2	2
	24	1	0	2
	2	1	1	2
Spanish	25	51	51	53
	18	8	6	6
	10	0	1	1
	2	1	3	3
Arabic	47	3	4	4
	2	1	1	1
	63	56	57	55

1. Detailed Test Data Description

Due to various course lengths, some sections of courses are in session during more than one fiscal year. The parameter $PCDUR_t$, found in constraints (2) and (8) account for any previously scheduled sections requiring consideration in OSI. This parameter is easily formed from the number of sections and weeks they extend into fiscal year 1994, contained in Table 4.

TABLE 4

SUMMARIZED TEST DATA OVERLAP

The number of sections and the length of time they extend into fiscal year 1994. These values are used to form the parameter $PCDUR_t$, which indicates the number of instructors committed in each week due to 1993 scheduling decisions.

Language	Number of Sections	Length
German	2	3
	2	10
	.5	24
	3	28
Spanish	6	10
	4	16
	9	22
Arabic	5	1
	6	5
	5	10
	5	11
	6	14
	6	18
	6	26
	1	18
	3	33
	6	37
	6	43
	1	46
	6	47
	5	51
	3	56
	3	60

The German language was considered a representative small data set. There was on average 13 sections to schedule for each fiscal year, as shown in Table 3. Course lengths did not exceed 34 weeks allowing substantial scheduling flexibility. There were several courses overlapping intc the new fiscal year schedule, as shown in Table 4. A unique case in the overlap was the existence of half a section being scheduled into the new fiscal year schedule. Half a section refers to a section of five students or less requiring only one instructor.

The Spanish language was chosen as the representative intermediate data set and required the scheduling of four times as many sections as the German language. It contained a 25-week course that the scheduler dealt with in two ways, either as a single 25-week course or the preferred manner, a 50-week course that was counted as two consecutive 25-week courses. There is no standard percentage used in determining the 25/50 week mix. Trail and error showed the best mix as nine 25-week courses and 21 50-week courses for fiscal year 1994 and the maximum number of 50-week courses possible for years 2 and 3. Other trial and error runs resulted in higher instructor year totals and/or extensive solve times.

The Arabic language was considered the representative large data set. Although the Russian language required more sections to be scheduled, as shown in Table 3, the Arabic

language contained a majority of courses 63 weeks in length. This 63-week course provided a substantial challenge for the scheduler and was therefore of great interest as a representative data set.

B. COMPUTATIONAL PERFORMANCE

The basic measure of effectiveness for OSI is the time required to obtain a feasible solution. The yearly schedules generated for the three test languages were shown to the program analyst and scheduler for their critique. Both verified the schedules to be accurate, complete and implementable.

1. Time Required to Develop Schedules

It takes the DLI scheduler as much as 3 days to develop a years' schedule for one language. The OSI models produce a three year schedule for one language in less than three hours. This is a considerable improvement in terms of hours required to develop a master schedule.

As shown in Table 5, for all three representative data sets, the solution times required to guarantee an optimal solution or a solution within 1% of optimal dramatically increase for all three languages. However, solutions guaranteed to be within 10% of optimal have approximately the same instructor year totals as indicated by the objective function values shown in Table 6.

Stauffer, G. L., "Class Scheduling: An Opportunity for Innovation," *Educational Resource Information Center*, pp. 1-

The OSI models with solutions guaranteed to be within 10% of optimal produce face valid schedules for all languages. Based on the results of the representative data sets shown in Tables 5 and 6, the 10% level was chosen as the basis for all subsequent language testing.

In order to solve OSI_1 optimally a cascading technique can be used. This approach keeps X_{it} as integer variables in year one, while allowing X_{it} in years two and three to solve as continuous variables. Once solved, $TMAX_1$ is fixed to its optimal value and X_{it} in years one and two are constrained to be integer variables while X_{it} in year three is allowed to be continuous. Upon solving, $TMAX_2$ is fixed and the original OSI_1 model is solved. Table 7 shows the promising results of this approach. However, the cascading technique was not investigated until after the computational work reported in this thesis. Since results obtained with solutions guaranteed to be within 10% of optimal already demonstrated face valid schedules superior to those created by manual method, the computational work was not repeated with the cascading technique.

TABLE 5

SOLUTION TIMES FOR THE OSI MODEL

The solution times in minutes are obtained using the AMDAHL 5990-700A mainframe and show the ability of OSI to quickly develop schedules that took up to three days to develop manually. The time represents the minutes needed to guarantee a solution within the indicated percent of optimal. The (**) represent a solution time in excess of 5 hours.

Language	OSI_k	10%	5%	1%
German	1	17.37	13.8	**
	2	9.49	10.1	**
	3	106.25	**	**
	4	28.53	**	**
Spanish	1	39.48	51.53	**
	2	2.33	2.57	3.46
	3	8.13	7.27	10.63
	4	4.68	3.49	4.05
Arabic	1	22.10	19.5	18.7
	2	4.34	4.32	4.52
	3	5.31	5.48	5.84
	4	6.47	6.13	**

TABLE 6

INSTRUCTOR YEAR TOTALS FOR FY 94

This table demonstrates that objective function values guaranteed within 10% and 5% of the optimal do not change appreciably, whereas Table 5 shows a significant increase in time. The 10% setting is therefore recommended.

Language	10%	5%	1%	Optimal LP Solution
German	44	44	**	42.0
Spanish	172	172	**	163.56
Arabic	428	428	428	426.0

TABLE 7

CASCADING RESULTS OF OSI_1

Results of OSI_1 using a cascading technique to obtain the optimal solution. Solve times appear in minutes. This technique is strongly recommended for further development and ultimate adoption by DLI.

Language	Solve Time	OSI_1 Optimal Solution
German	3.18	43.0
Spanish	2.07	164.0
Arabic	0.48	426.0

2. Manual Versus Model Comparisons

OSI_1 and OSI_2 were run to compare instructor year totals over the next three years for all applicable languages. OSI results, summarized in Table 8, provide a substantial reduction in instructor years. Further reduction in the OSI totals are possible since the models always assign two instructors to each section (recall sections of five or less students can be scheduled with one instructor but this is not the preferred method). As an example, the models' results for Japanese (36 instructor years) can be reduced to the manually projected total (34 instructor years) since two scheduled sections contain only one student.

The average instructor salary with benefits is approximately $64,700 (GS 9, Step 5) (OPM, 1992). The results in Table 8 show a decrease in instructor year totals over a three year period. This decrease equates to an approximate savings of $6,545,800 over the next three years.

The OSI_2 model can minimize turbulence between instructor totals from year to year. The current manual methods only attempt at this concept is to try to reduce student input through ATRRS. Figures 3, 4 and 5 show the results of comparing manual versus model weekly instructor totals, for each representative data set in fiscal year 1994. OSI_2 shows consistency in instructor totals not only the first

TABLE 8

MODEL VERSUS MANUAL COMPARISON

Instructor year totals for fiscal years 94, 95, and 96 using OSI_1 and OSI_2 compared to projected manual totals. Cost/Savings is based on salary and benefits of a GS-9 (Step 5).

Language	Projected Totals	Model Totals	Difference	Cost/ Savings
Russian	377	360	17	$1,099,900
Arabic	438	428	10	$647,000
Spanish	182	172	10	$647,000
Korean	226	224	2	$129,400
Chinese	134	128	6	$338,200
German	53	44	9	$452,000
French	35	30	5	$323,500
Czechoslovakian	45	34	9	$452,000
Vietnamese	43	34	9	$452,000
Persian	60	52	8	$517,600
Polish	40	38	2	$129,400
Japanese	34	36	(2)	($129,400)
Turkish	18	14	4	$258,800
Thai	26	20	6	$338,200
Italian	12	12	0	0
Hebrew	28	24	4	$258,800
Ukrainian	18	16	2	$129,400
Tagalog	22	22	0	0
Portuguese	12	12	0	0

year (FY 94), but over the two remaining years where the manual method shows a noticeable fluctuation in instructor totals from year to year.

Figure 3 indicates OSI_2 provides a larger instructor year total for the Arabic language than manual methods for FY 94. However, as shown in Table 8, the three year reduction in Arabic instructor years is ten, indicating a decrease in the total number of instructors needed over the three years. The model's FY 94 level of 146 instructors is the same as in FY 93, thus providing no change in instructor levels the first year. It is possible to reduce the FY 94 total from 146 to 144, if reduction is mandated.

Making predictions based on "what if" scenarios currently requires the scheduler to manually reproduce the master schedule. The OSI model enables the scheduler to pick the version of the model in which any predictions will be based and make a separate run with the hypothetical data.

Cases may arise where the minimum instructor year total for a single year, produced by the model, exceeds the maximum allowable DoD figures for that year. Manually the schedule would require a complete rework that may take an additional 2 or 3 days. Using the OSI_2 model and changing the three year instructor year totals (TOTINST), the turbulence between years could be reduced to some extent forcing the total for that single year down. For example, in a previous

OSI_2 test run, the minimum instructor year total for the Arabic language was 424 with yearly totals being 162, 132 and 130, respectively. To adjust the high year (162) the instructor year total was increased. As shown in Table 9, an increase of approximately 1% in the instructor year total significantly reduced the year to year turbulence. The above example strengthens the necessity of treating each OSI model separately.

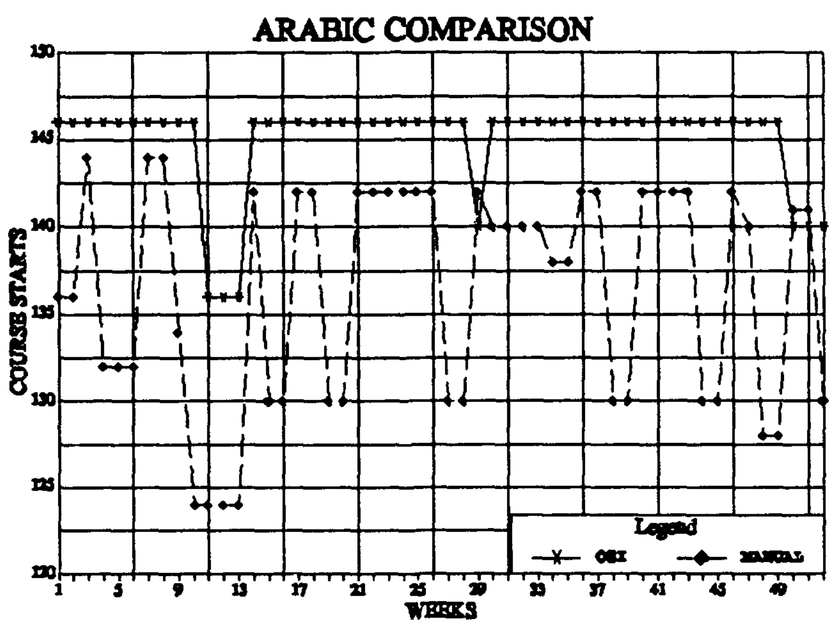

Figure 3

SPANISH COMPARISON

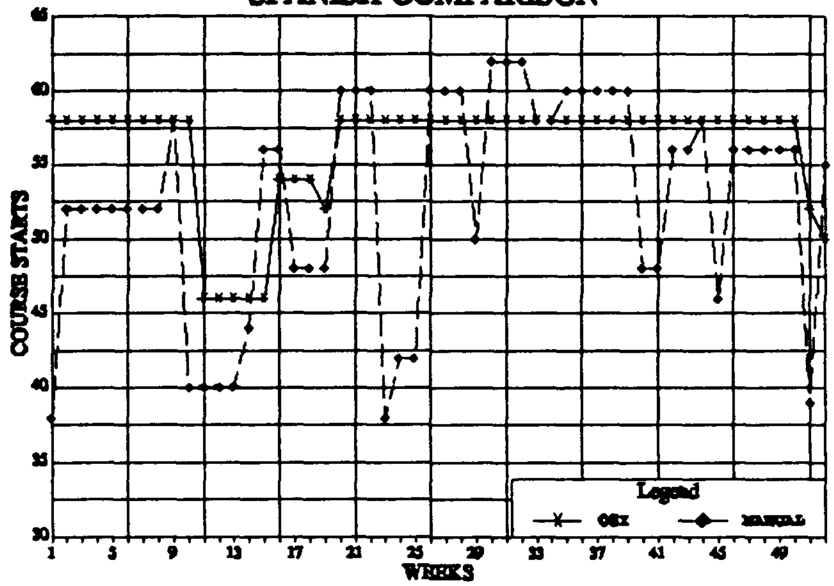

Figure 4

GERMAN COMPARISON

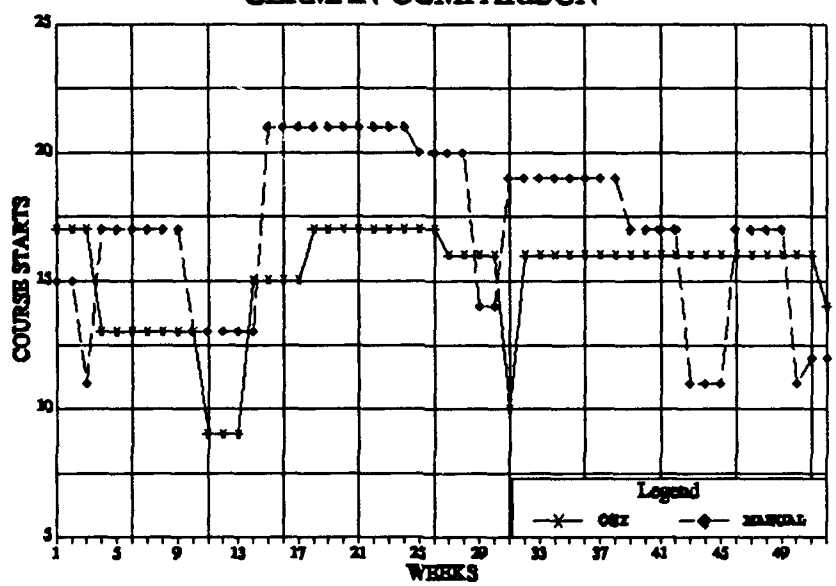

Figure 5

TABLE 9

OSI_2 RESULTS FROM INCREASING INSTRUCTOR TOTAL

Increasing the instructor year totals (as little as 1%) may allow OSI_2 to significantly reduce the turbulence from year to year.

Instructor 3 year Total	Instructor 3 year Increase	Instructor Yearly Totals		
		Year 1	Year 2	Year 3
424	-	162	132	130
424	428	148	140	140
424	430	148	144	138
424	432	148	148	136

TABLE 10

3 SECTION START COMPARISONS

The table shows a comparison of manually scheduled three section starts and the results of OSI_3 for FY 94.

Language	Scheduler	Model
German	3	3
Spanish	15	18
Arabic	9	17

The efforts to maximize three section starts in the OSI_3 model are shown in Table 10. Manually the scheduler obtains three section starts on a trial and error basis. OSI_3 maximizes the number of three section starts.

An effective method of comparing results of the OSI_4 model is to compare instructor down time. Figures 3, 4 and 5 show a graphical comparison of OSI and the manual method for FY 94. As these figures indicate, the OSI schedule produces significantly less fluctuation over FY 94, implying less instructor idle time. Manual schedules were not available for fiscal years 1995 and 1996, but as Figure 6 shows OSI_4 continues to have only minor fluctuations in instructor levels over all weeks.

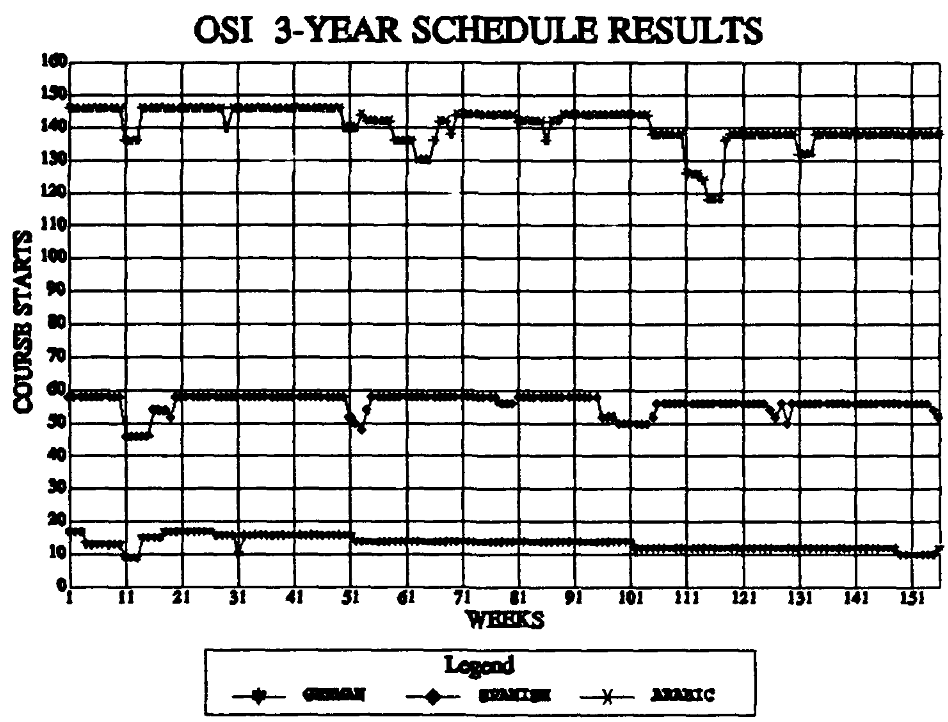

Figure 6

V. CONCLUSIONS

The OSI model produces face valid yearly master schedules in less than three hours for each language on the NPS AMDAHL 5990-700A mainframe. These schedules are better than the manually developed schedules in all areas of concern. The models yield a smaller instructor year total, employ a more constant work force from year to year (minimal turbulence), and require significantly less time to produce face-valid schedules. The separate objectives of OSI provide the scheduler the flexibility to review scheduling alternatives quickly and efficiently. OSI develops face-valid schedules that can be implemented as is; however, the most beneficial aspect of the model is it will assist the DLI scheduler in developing feasible schedules at a much faster rate.

The Base Closure and Realignment Commission has forced DLI to investigate alternatives to cut spending. In an attempt to remain open, DLI recently announced the layoff of more than 100 instructors from various languages (The Herald, July 26, 1993). These layoffs were primarily based on changing language trends. The OSI model can provide DLI with potential additional savings in excess of $6.5 million over the next three years by further reducing their instructor work force without sacrificing its mission.

After reviewing the results of OSI the program analyst at DLI began steps to permit the implementation of the model. The DLI scheduling office has acquired a NPS mainframe account and updated their hardware to fully implement the model. A user interface on their NPS mainframe account is in the process of being created by the author to provide the scheduler direct access to the model.

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